Raytheon Missile Systems
Experimental License KA2XAG Renewal Application
File No: 0193-EX-CR-2017

Tucson Test Facility
Explanation of Experiment and Use of Spectrum

Background:

This application is filed to renew experimental license KA2XAG to continue operations at the radar cross section testing facility (Tucson Test Facility or TTF) operated by Raytheon Missile Systems (RMS) in Tucson, Arizona. This application is for RMS to use this spectrum for independent research and development (IRAD) of products. The same facility is used for identical testing by RMS pursuant to government contracts. The use of the facility for government contractual purposes is the subject of parallel Navy frequency assignment requests. After numerous meetings with both the Navy and the Federal Communications Commission (FCC) in 2008, 2009, and 2011, RMS was instructed that this facility requires both the Navy frequency assignment and an FCC experimental license, as it has in the past. A modification to the existing license was granted very recently, and this renewal application seeks to renew the operations authorized under the modified license, KA2XAG.

Description of the Research Project:

RMS builds systems used for national security and defense. Creating products and systems that are difficult to detect is an important part of developing new technologies that keep our nation safe. While much of the company's work is performed on government contracts, some work is done independently to develop new ideas that may be useful to RMS's customers. That IRAD testing requires use of the Tucson Test Facility, and an experimental license is required for operation. The nature of the research is to determine the radar cross section of various objects under test. Radar pulses are narrowly focused to bounce off those objects, and the radar returns are evaluated to determine the profile of the object. There is no way to measure the radar cross section of an object without using a radar, the purpose of the facility for which this license renewal is being filed.

This facility has had an experimental license, KA2XAG, from the FCC for over 20 years. This renewal application proposes to extend ongoing operations at the TTF.

The spectrum will continue to be used in the same way: stepped frequency radar testing. The object under test is placed on a pylon down range from the radar transmitter; the pylon rotates in 0.1 degree azimuth increments, and at each increment the radar systems step through the authorized frequencies, measuring both polarizations to determine the return from the object.

The signal generator requires some measurable time between pulses to avoid overheating, and each pulse has a maximum duration of 70 nanoseconds. Table 1 below presents information on total test time, total time on a frequency and other data that helps to illustrate the brevity of the RF signal use.

At its most productive, the range can only test six to eight objects per day, allowing for changing the object aspect, cooling the signal generator, and performing the requisite computations that must be run between pulses. Normally, the range only tests one or two objects per day.

Synopsis:

- Test Range: Used for radar cross section testing.
- Frequency usage: Tests step across frequency bands in 10 MHz steps.
- Time of Use: 70 nanoseconds per frequency step, very short pulse duration.
- Spectrum needed: 100 MHz to 18 GHz, and 32 to 39 GHz, as limited on license.
- Azimuth of operations: 237 degrees, beamwidth of about 2 degrees
- Range design: Antennas are directional & tilted downward to minimize spatial dispersion of the radiated power.

Technical Details of Testing:

TTF operates a low power instrumentation test range. Most testing currently steps across the 100 MHz - 18 GHz and 32-39 GHz bands, as limited by the license. The transmissions are made in 10 MHz steps, with a pulse width of 70 nanoseconds and the beam narrowly focused to illuminate the test objects. Although the power level and antenna gain for these transmissions appear to be high, the narrow beamwidth and downward tilt of the antennas serve to minimize any potential interference effects associated with the test transmissions; furthermore, the duration of the pulses is so short that they will not be detected by typical radio receivers.

As far as the measurement procedure is concerned, the test object is put on a turntable down range from the radar, and the transmitter is pulsed to capture complete data on the return from the object. The radar receiver acquires the reflected signal, which is subsequently processed to determine the time-domain response of the object under test.

Test Time:

Tables 1 and 2 below show how Raytheon calculated the maximum time of use for any frequency used on one day as well as the maximum total amount of time that RF may be emitted within a single day. Regardless of how many frequencies are being tested, the total amount of time that any frequency would be in use on a single day is never more than **387** milliseconds.

Table 1 shows the total amount of time spectrum is in use while testing is being conducted across the combined range consisting of the existing licensed spectrum and the spectrum requested under this modification application: that is, 100 MHz – 18 GHz and 32 – 39 GHz. Table 2 shows the theoretical total amount of time of spectrum would be in use when testing is conducted only on the additional spectrum requested under this modification application, 100 MHz to 2 GHz. Given the license restrictions, the spectrum use will be even less than that calculated in Table 2.

All testing steps through authorized frequencies, pulsing at 10 MHz intervals, with each pulse being 70 nanoseconds in duration.

Table 1		**All Spectrum: 100 MHz - 18 GHz and 32 - 39 GHz**		**Calculations show use of a single frequency and total time of spectrum use per day**
Factor:	_	**Amount**	_	**Notes**
# of test angles		3600		
# of radar sweeps through all frequencies/angle		128		Multiple Sweeps needed for Fast Fourier Transform
total number of sweeps/pattern		460800		a pattern is the full set of sweeps through every angle and at each frequency
Number of polarizations		2		vertical and horizontal
pulse width (sec) - per frequency		0.00000007		70 ns pulses, time of use of the frequency per sweep
Time (sec) on a frequency per pattern (all 460800 sweeps)		0.064512		
maximum number of patterns run each day (different objects or different parts of an object)		6		Typical use is 6 patterns per day
Total time per day on a single frequency, in seconds (maximum use is 6 patterns per day)		0.387072		387 milliseconds total use per day
interval between frequencies tested (MHz)		10		testing steps across spectrum, pulsing for 70 ns every 10 MHz
Number of frequency steps for all spectrum		2490		the system steps through the frequencies in 10 MHz steps, for a total of 2490 steps
Maximum spectrum use per day - all frequencies included (sec)		963.80928		Total spectrum time used during a day of testing
Maximum spectrum use per day, including all frequencies (minutes)		16.063488		

Table 2	**Spectrum in use: 100 MHz - 2 GHz (theoretical maximum, since the license has limitations)**	**Calculations show use of a single frequency and total time of spectrum use per day**
Factor:	**Amount**	**Notes**
# of test angles	3600	
# of radar sweeps through all frequencies/angle	128	Multiple Sweeps needed for Fast Fourier Transform
Total number of sweeps/pattern	460800	a pattern is the full set of sweeps through every angle and at each frequency
Number of polarizations	2	vertical and horizontal
Pulse width (sec) per frequency	0.00000007	70 ns pulses, time of use of the frequency per sweep
Time (sec) on a frequency per pattern (all 460800 sweeps)	0.064512	460,800 sweeps and 2 polarizations
Maximum number of patterns run each day (different objects or different parts of an object)	6	Typical use is 6 patterns per day
Total time on a single frequency, in seconds (maximum use is 6 patterns per day)	0.387072	387 milliseconds total use per day
Interval between frequencies tested (MHz)	10	testing steps across spectrum, pulsing for 70 ns every 10 MHz
Number of frequency steps for this sub-spectrum	190	the system steps through the frequencies in 10 MHz steps, for a total of 190 steps
Maximum spectrum use per day - all frequencies included (sec)	73.54368	73.54 seconds of total spectrum use in a day, if 6 patterns are collected on the 100 MHz to 2 GHz sub-band.
Maximum spectrum use per day, including all frequencies in the sub-band (minutes).	1.225728	Total time of RF use for a day, in minutes

Description of the Test Plan:

The time of RF use for data collection for any given test object is short. An object is placed on the test range 520 feet from the transmitting antennas; and for most of the testing, the transmitter is pulsed at each frequency, from 100 MHz to 18 GHz and 32 to 39 GHz, in 10 MHz steps (as noted above, each pulse is 70 nanoseconds in duration). The radar pulses at a single frequency 128 times for the system to correlate the signal using a Fast Fourier Transform (FFT). Then, it steps to the next frequency, pulses again 128 times, and steps on to the next frequency. After a complete set of frequency steps has been performed, the polarization is changed and the frequency stepping is repeated at the same angle. The object on the turntable is rotated thru 360 degrees in 1/10 degree increments, with the frequency stepping at both polarizations repeated at each angle. Figure 1 below shows graphically the 1.2% duty cycle on a single frequency, and Figure 2 shows the overall duty cycle on a frequency for a single day which is below 0.006%.

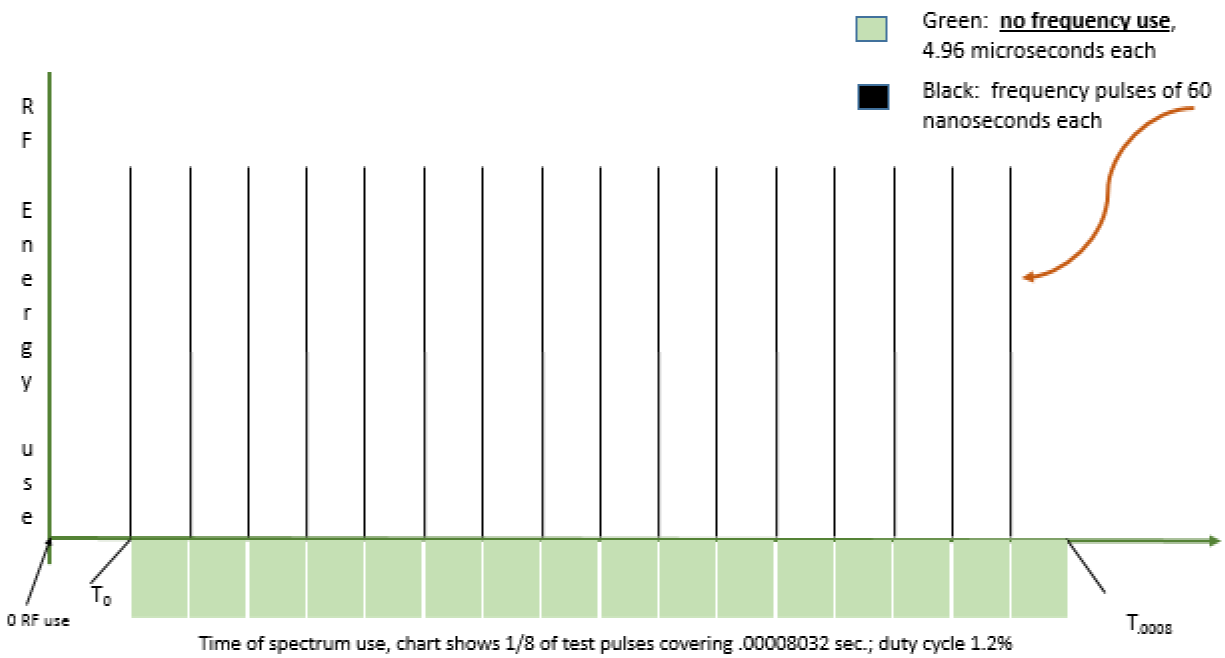


Figure 1. Illustration of Duty Cycle for 128 Pulses at a Frequency

- Black & green lines represent 128 cycles of on time (black) and settling time (green) = .00064256 seconds, for any frequency step
- Purple line represents time when system is pulsing in ***other*** spectrum, with duty cycle < 0.006% for test day

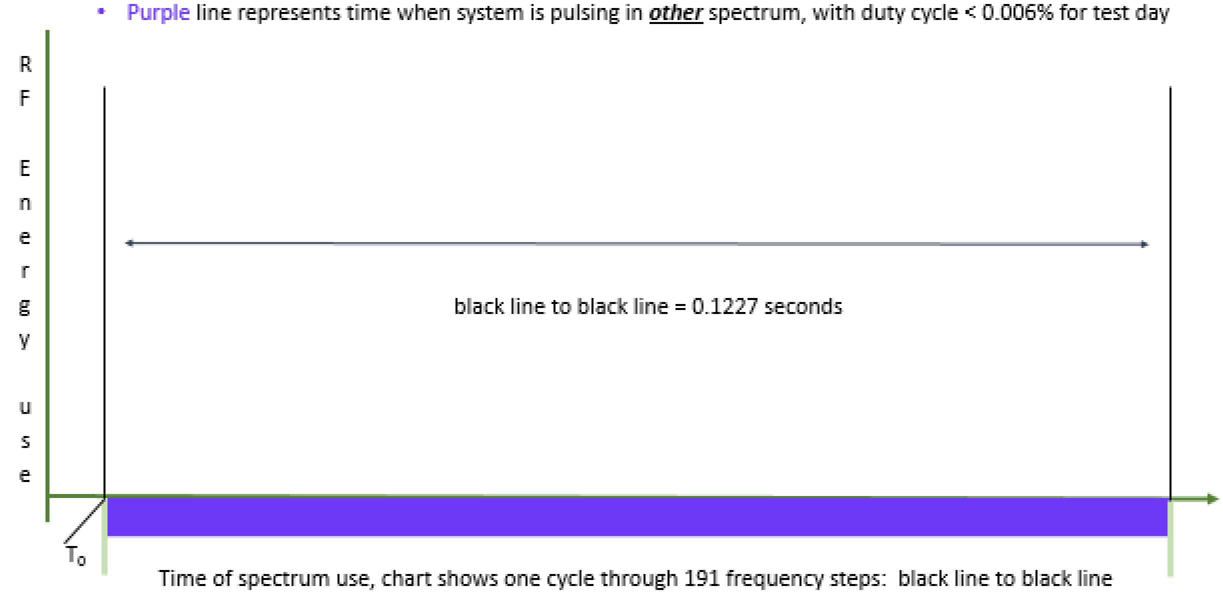


Figure 2. Illustration of Daily Overall Duty Cycle of a Frequency

If the weather is perfect, up to 6 items, or patterns, can be tested each day. On windy or rainy days, or when there are nearby thunderstorms, there is no testing because of safety issues. Typically, six patterns are completed in a day. The RF is in use, across all frequencies, for a total of 16 minutes. The total time of RF use for any single frequency is only 387 milliseconds spread across an entire day.

Evaluation of Interference Potential

Raytheon has run tests using a spectrum analyzer to measure the signals from the TTF range, and the spectrum analyzer did not register use of spectrum at all, because the pulse width of the signals is so short.

Geography Limits Interference Potential:

TTF is located in a relatively unpopulated area, which also minimizes the possibility of any potential interference. At the request of the FCC and others, RMS researched numerous questions, including whether there was potential impact on FM radio reception from test. RMS was also requested to provide additional theoretical analyses of the signal strength in the surrounding area.

Azimuth of Operations:

The system is designed to use narrow radio beams, utilizing antennas with high gain. The antennas are pointed at azimuth 237, which is nearly perpendicular to the runway at nearby Tucson International Airport. This direction was selected because it makes the best use of geometry: pointing toward unpopulated desert, but also shielding the backlobe with a building and protecting airport operations. The narrow beamwidth minimizes any radiation in the side lobes.

Voice Communications Equipment and FM Receivers Receive No Interference:

Raytheon's research indicates that voice communication equipment will not respond to 70 nanosecond signals because the signal duration is too short for a typical receiver to process. In addition, FM receivers normally reject pulsed signals, and the squelch on most commercial receivers rejects signals that are shorter than one millisecond in length. One frequency sweep from the TTF has less effect on a voice communications radio than a lightning strike. FM receivers are designed to reject amplitude variations in the received signals, which further reduces the likelihood of interference. Motorola, which makes a variety of handheld and fixed-location voice communication products, stated that voice communications equipment will not respond to 70 nanosecond RF bursts.

In the past, Raytheon has verified that TTF does not interfere with voice communications equipment operating on or near the spot frequencies. RMS engineers tested using a Motorola handheld radio on the TTF range. The radio was tuned to 155 MHz and placed in the TTF main antenna beam with the TTF transmitter also set to 155 MHz. As expected, the radio did not respond to the maximum-power emissions from TTF's test system. The tests were repeated on 815 and 1300 MHz, and in all cases the radios registered absolutely no response to the transmitted signals. Because of the stepped nature of the proposed testing, no interference is expected in the frequency bands 100 MHz to 2 GHz. The pulse width of 70 nanoseconds is so short that it will not affect receivers on these frequencies.

Raytheon put FM radios on the pylons on the range, turned on the TTF transmitters, and there was no interference.

Raytheon also tested aircraft radios, AM radio receivers, and commercial band radios in the 400 MHz band: there was no interference to any of those radio receivers from operation of the TTF range.

Need for Continuous Spectrum:

RMS needs continuous spectrum for its testing to get valid information concerning the radar cross section of its new products. Thus, the testing is mostly conducted at 10 MHz intervals.

Spectrum Plots Show Very Weak Signals beyond the Test Range:

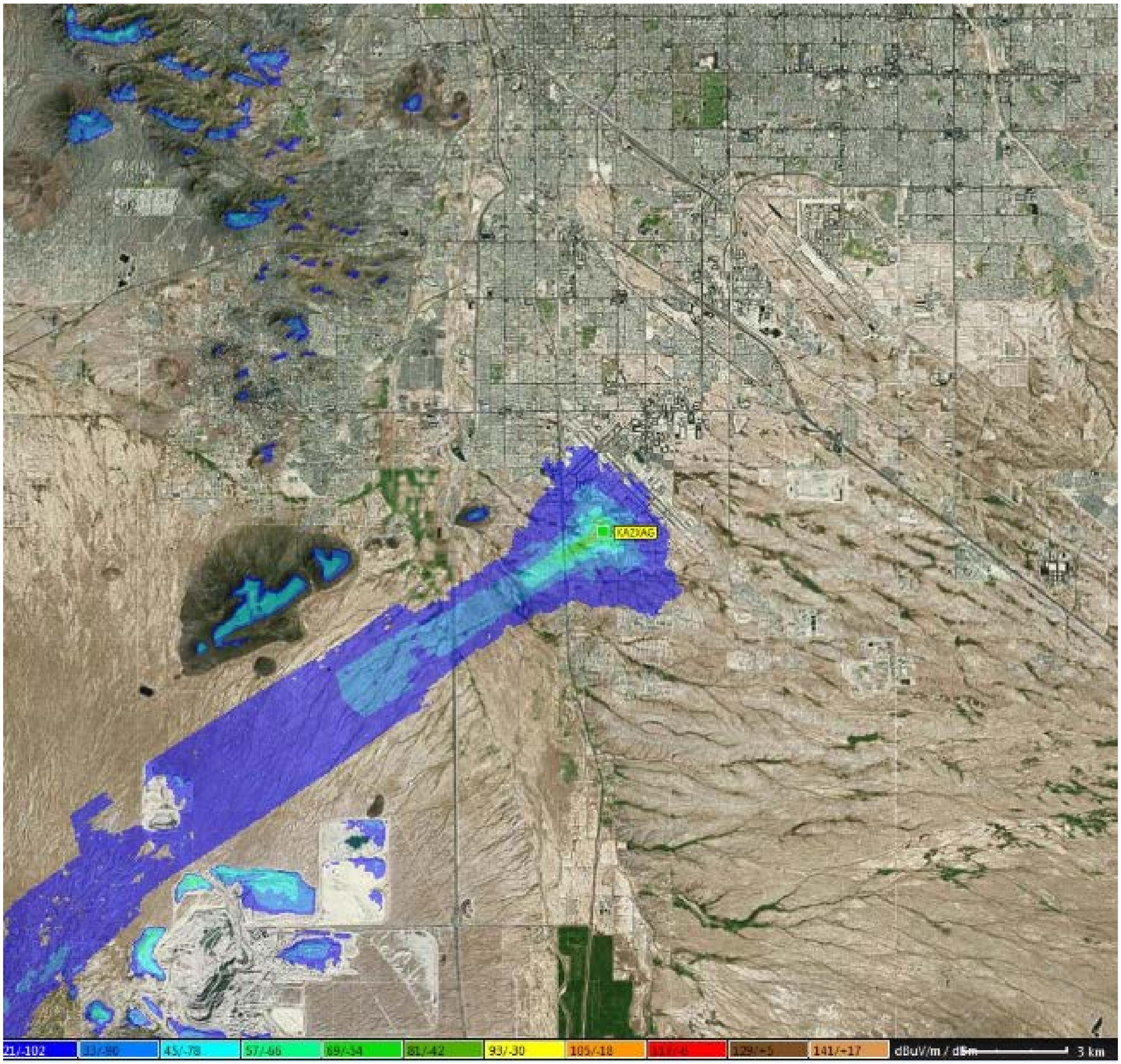
To illustrate the rapid drop off of the signal in all frequency bands, RMS ran theoretical spectrum analyses using Hertz Warfare software. The Hertz Warfare plotted predictions do NOT take into account the attenuating effect of buildings around the transmitters. The plots show significantly more signal propagation than actually occurs in the real world, because the surrounding buildings absorb signal power and attenuate propagation.

The spectrum plots below indicate that the signal levels would **never be greater than -58 dBm** beyond the test range. These plots were generated with the latest version software and show more detail of signal propagation, although they still do not account for building attenuation. With the short pulse width, the possibility of harmful interference to any other radio use is minimal. Moreover, because the spectrum analyses do not take into account the attenuating effects of buildings, they predict much stronger signals than will actually be present during a test.

On each of the spectrum plots shown below, the power level is 100 W, and the antenna gain is factored into the signal propagation. The color scale varies for each frequency due to the nature of the software. A note regarding the color scale is presented below each plot.

200 MHz signal propagation:

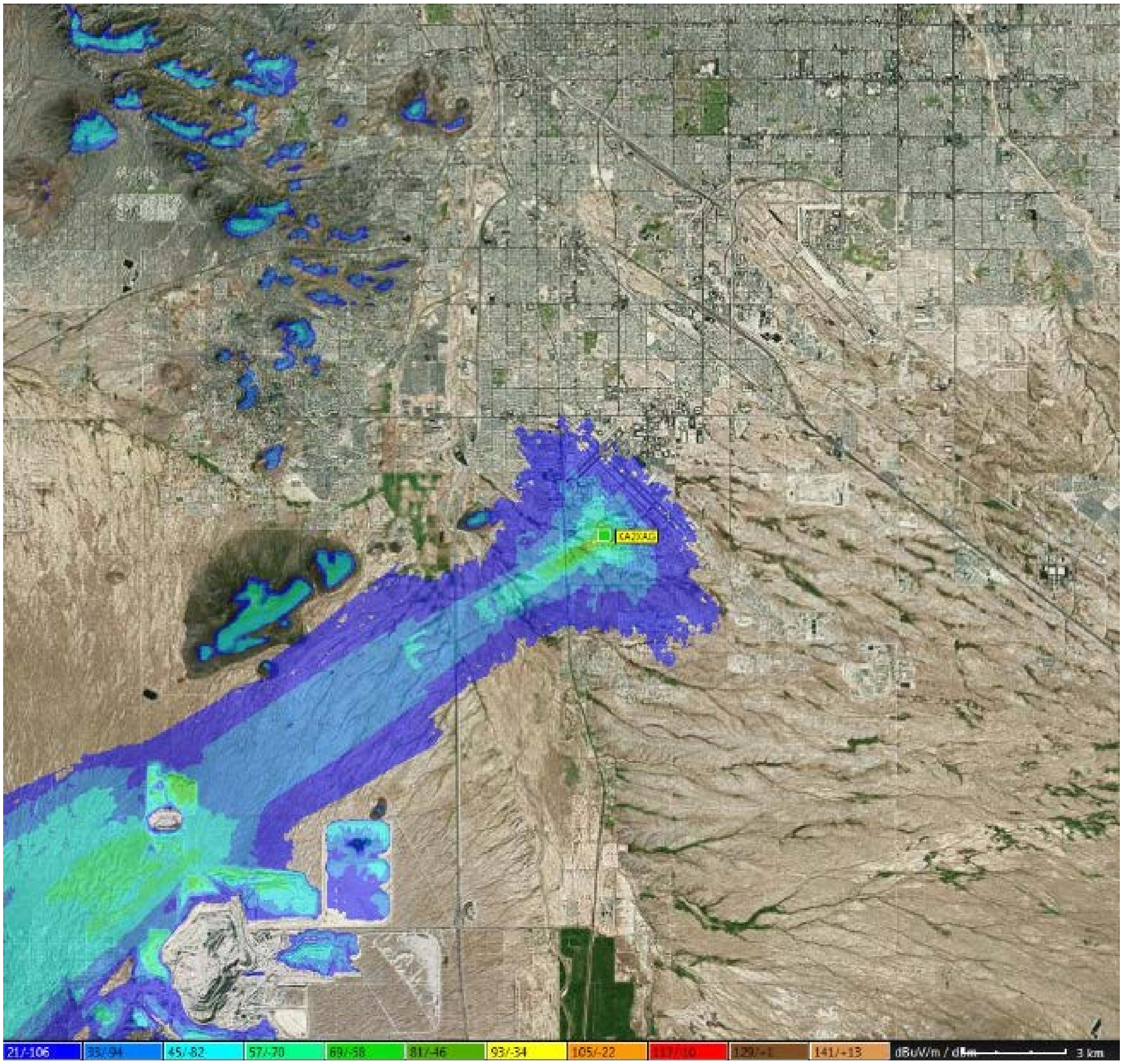
(Scale: 1 inch = 3 km)



Note on Scale: dark blue is -102 dBm

325 MHz Signal Propagation

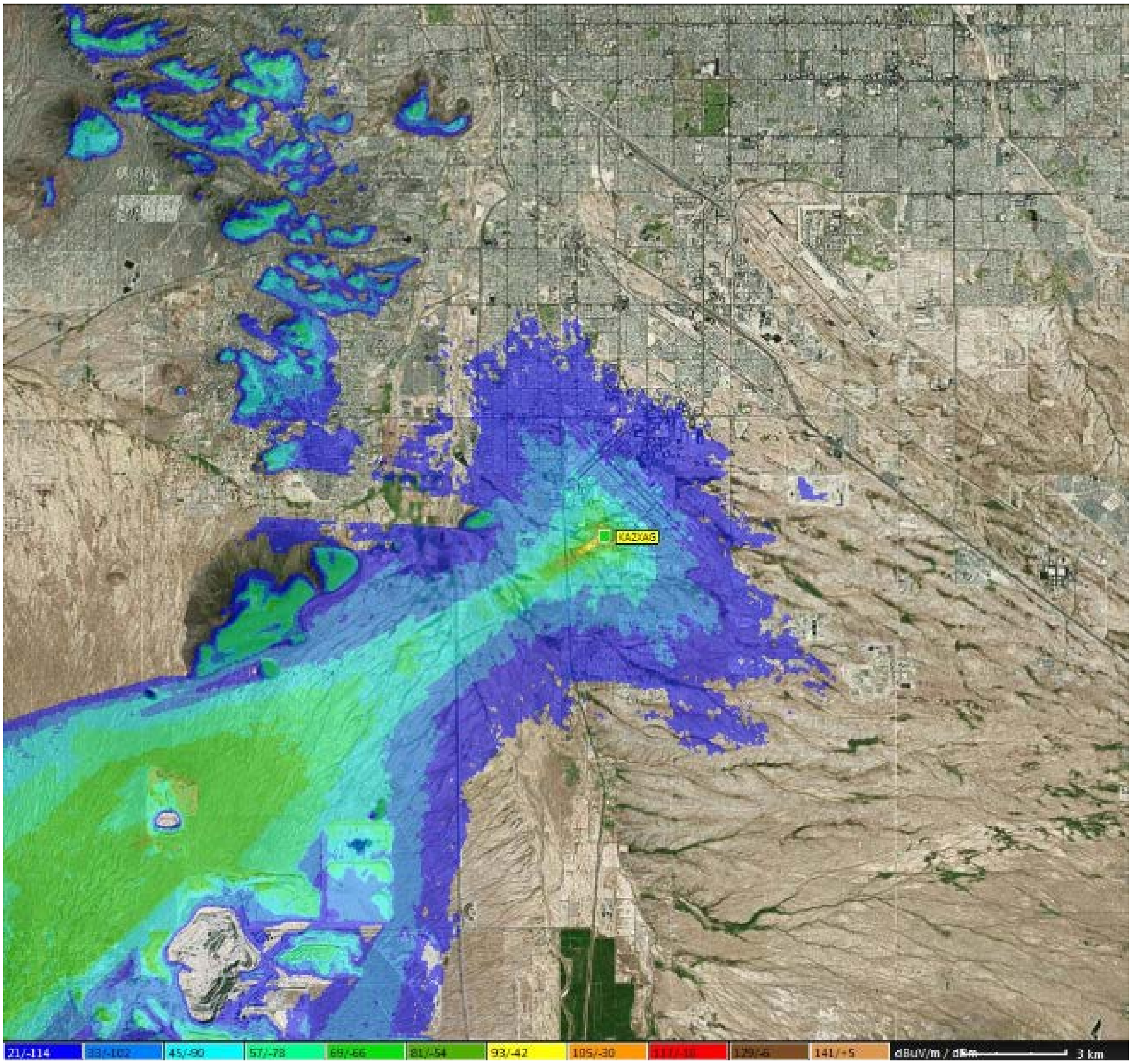
(Scale: 1 inch = 3 km)



Note on Scale: dark blue is -106 dBm

800 MHz Signal Propagation:

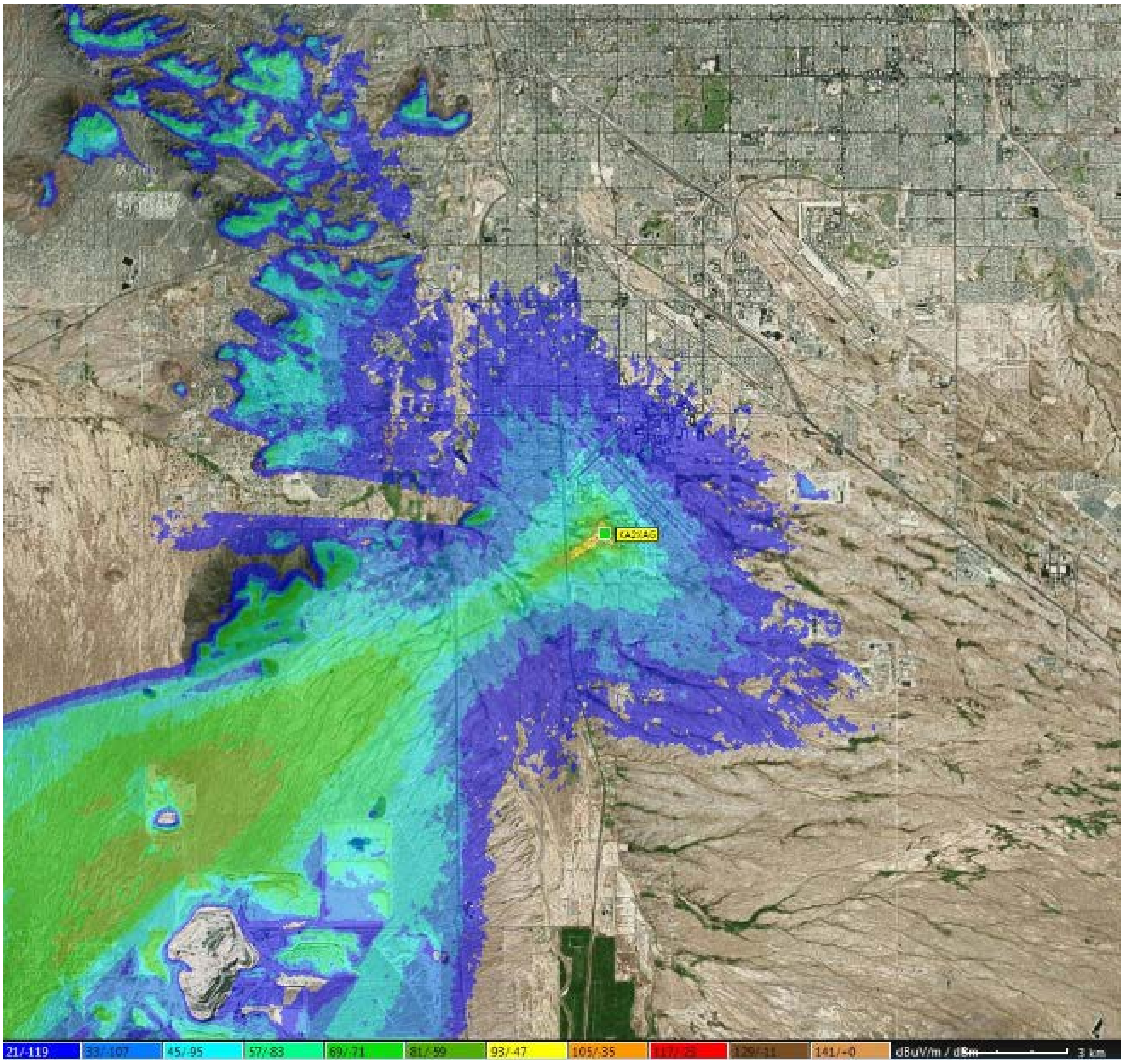
(Scale: 1 inch = 3 km)



Note on Scale: dark blue is at -114 dBm

<u>1400 MHz Signal Propagation</u>:

(Scale: 1 inch = 3 km)



Note on Scale: dark blue is at -119 dBm

The Hertz Warfare plots indicate that the signal strength from the TTF operations is generally weaker than -70 dBm once the signals go beyond the TTF range. Analysis of the spectrum plots, coupled with Raytheon studies of radio noise floor data, indicate that the TTF signal will blend into the local radio noise. As shown in previous applications RMS has filed for operations at this test range, the radar returns used at the range are down in the noise, which has led to the extensive testing performed to use correlation data to discern the real signals from the radio noise. Given the predicted weakness of the proposed radio signals, it would be reasonable to expect that a grant of this renewal request will not lead to harmful interference to any of the surrounding area.

Further, the scattering of the energy will reduce any chance of interference. The plots do not account for the attenuating effect of buildings; as a result the real signals will be much weaker. Finally, studies have shown that most commercial communications systems are not subject to interference from any signals weaker than -60 dBm. When the weak signals are assessed in combination with the short pulse width, the chance of harmful interference nears zero.

No Harmful Interference to GPS:

The FAA has carved out the GPS bands from those that Raytheon is authorized to use. No testing will be conducted on GPS frequencies, therefore there is no expected harmful interference to GPS.

Occupied Bandwidth and Pulse-Width:

The calculated occupied bandwidth of 10 MHz is used for most of the transmissions at the test facility. The measurement system was designed to ensure that each test gives an accurate picture of the radar cross section of the test object for each specified 2 MHz of spectrum. The transmissions were tested to show that the radar pulses use very narrow bandwidth, about 1 MHz at 3 dB down from peak power and less than 2 MHz at 20 dB down from the peak power.

A 70 nanosecond pulse-width was selected to ensure an accurate measure of the object being tested. The pulse needs to be wide enough to create an RF envelop that illuminates the extent of a typical test object, and it must be narrow enough to ensure that the return signals arrive within a specified time window. All of the calculations presented in this filing are based upon a pulse-width of 70 nanoseconds. There are some objects for which the pulse-width used is actually shorter, as little as 30 nanoseconds. Typically, the pulse-width is 60 ns, but Raytheon based its calculations on a "worst case scenario."

Stop Buzzer Point of Contact:

Should there be any instances of interference, the stop buzzer point of contact is:

Thomas J. Fagan, Spectrum Manager
Raytheon Missile Systems
520-794-0227 (office)
520-465-7087 (cell)

Procedural History and Coordinations:

As noted earlier in this exhibit, Raytheon filed an application to modify KA2XAG on April 22, 2014. That modification was granted on April 22, 2015 – one year later. In the course of seeking that modification to include the use of some frequencies between 100 MHz and 2.0 GHz, Raytheon sought and obtained consent or concurrence from a number of parties including AFTRCC and FAA.

Further, Raytheon was required to get consent from FirstNet, prior to the processing of the application. FirstNet was not operational in Arizona in 2014, so FirstNet required Raytheon to seek the consent of the state and local public safety licensees. Those licensees include the Arizona Department of Public Safety and the committee of public safety licensees that is run by the Arizona

Department of Public Safety. Raytheon successfully sought and obtained the required consent from the state-wide and local licensees. That consent was submitted as an attachment to the 2015 renewal, 0206-EX-RR-2015.

If necessary, Raytheon will coordinate again to secure the required concurrences/consents for approval of this renewal request.

Conclusion:

In order to acquire the directional RF transmission radiated by the TTF radar, a receiver would actually have to be looking for it: the receiver would have to be located in the forward plane of the transmitting antenna, with a major antenna lobe facing toward TTF. The receiver would also need to be looking to acquire the radar pulse at precisely the frequency and instant that the radar is transmitting, and it would need to be sufficiently sensitive to detect the short duration and extremely attenuated signal. Standard radio receivers are not designed to process signals at the pulse width used by the test facility, thus any detected RF signal will be filtered out by receivers that are sensitive enough to detect signals at such low levels.

For questions about this application, please contact Tom Fagan, 520-794-0227 or tjfagan@raytheon.com, or Anne Linton Cortez, 520-360-0925 or alc@conspecinternational.com.